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Evaluation of Treated Wastewater Quality Changes through the Vadose Zone

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Abstract

Due to water challenges in arid and semi-arid regions including water scarcity and increasing demands, wastewater reuse in irrigation is becoming more widely practiced. This paper presents a case study for Sadat City, Egypt, to assess the impacts of using treated wastewater (TWW) in irrigation on soil and evaluating the natural attenuation of the TWW in the vadose zone. A field and laboratory program was conducted to identify the hydraulic properties of the soil and the contaminant concentration in water and soil. Water flow and solute transport are simulated in the vadose zone using HYDRUS 1D for five soil profiles in the study area through 50 years from 1992 to 2042. Six contaminants of concern were selected to simulate (Mg, Cl, Fe, NH_3, NO_3 and Fecal Coliform to study the bio-clogging effect on the soil). Six irrigation scenarios were selected to simulate flow and transport according to thewastewater treatment (primary, secondary, oxidation pond, tertiary treated wastewater, tertiary for double field water duty and irrigation with two year rotation(primary treated wastewater and groundwater)). The results show the concentration of contaminants of concern which will reach to groundwater aquifer after the purification and soil leaching.The results indicate that the concentrations of contaminants of concern were affected sensitively by the initial concentration of soil columns.

Keywords: Wastewater, groundwater, vadose zone, HYDRUS 1D

1. Introduction

The world's freshwater resources are under increasing pressure due to the growth in population. In Egypt, renewable water resources are approximately 57 billion cubic meters (BCM)/year. More than 97% of these come from the Nile River. On the other hand, the water demand is increasing as a result of population growth, urban migration, and industrial development. Agriculture is the primary water consumer, representing 85 % of the total water demand.

As a result, the treated wastewater (TWW) reuse in agriculture is considered an important part of arid and semi-arid regions overall water resources balance. Egypt Government plans to use TWW to increase the cultivated area by 470,000 feddans.

In this research, a pilot area in Sadat City was selected as a case study to assess the use of TWW in irrigation, impacts on soil,and the natural attenuation of the TWW in the vadose zone. In this regard, field and laboratory experiments were conducted for the study area. This was followed by a numerical simulation using HYDRUS 1D to predict water flow and solute transport in the vadose zone.

2. Materials and Methods

2.1. Site description

The study area is located in Sadat City, shown in Figure 1. It extends between longitudes 30° 33' 45", 30° 39' 30" east and latitudes 30° 26' 35", 30° 29' 30" northcovering an area of 49.4 km^2.

2.2. Field investigation

The main objective of the field investigation isto estimate the physical and chemical properties of soil and the chemical characteristics of wastewater. In this regard, five boreholes were dug and five monitoring wells were installed in the study area. The collected data were used in HYDRUS simulations to assess the natural attenuation of treated wastewater through the vadose zone. The following were carried out:

- Identify physical and hydraulic properties of soil in the study area. This was achieved through digging five boreholes (soil columns) as shown in Figure 2. Five locationswere selected representing the background conditions:borehole No1represents the virgin soil; borehole No2, No4 and No5 represent lands which are irrigated with groundwater; borehole No3 represents lands which are irrigated with oxidation pond effluent in forest area.

- Evaluate wastewater and groundwater characteristics described by analysis of representative wastewater and groundwater samples.
- Determine the baseline condition of soil chemical characteristics. Chemical analysis for soil samples for the priority contaminants was carried out.
- The wastewater flow and solute transport, using HYDRUS-1D, were simulated in the five soil columns which represent the soil characteristics of the study area.

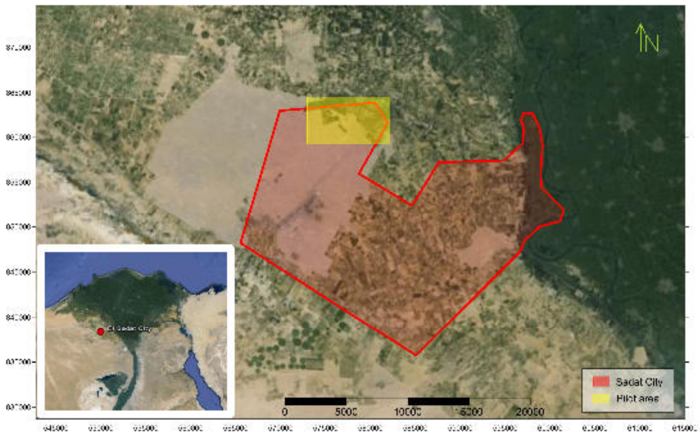


Figure 1. The study area location

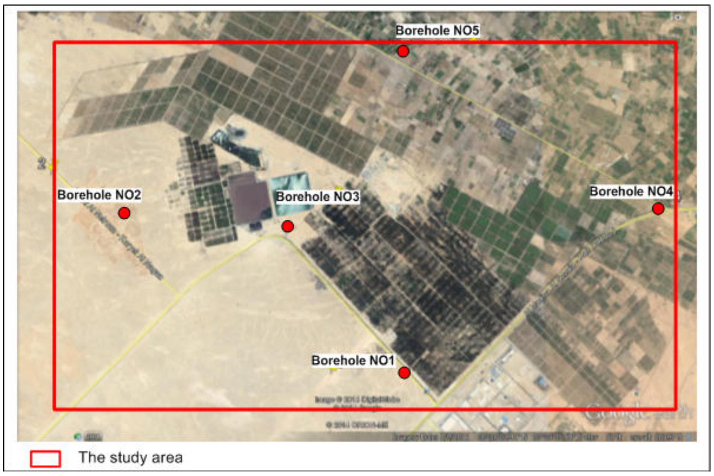


Figure 2. Boreholes location

2.3. Wastewater, soil and groundwater quality data

Wastewater samples were collected from primary, secondary, oxidation pond and tertiary wastewater treatment plants. The sampling program was conducted in January 2014 and repeated in June 2014, to account for seasonal variation in wastewater quality. The sampling period and frequency are 24 and 2 hours, respectively. To obtain average concentrations of different chemicals in wastewater the 24 samples were analysed separately.

Five soil samples were collected during the well digging. As the boreholes digging was conducted by adding bentonite, the soil samples were collected only from the first meter for each borehole because the water and bentonite will change the chemical properties of soil. Five groundwater samples were collected from the monitoring wells to define the initial conditions of groundwater in the study area.

The laboratory analysis of water samples followed the standard methods for the examination of water as described by the American Public Health Association (1998). The collected soil samples were analysed for: Magnesium by EDTA method according to Jackson (1973), chloride by the Ion chromatography (Ic) model DX500 chromatography system, Iron by inductively coupled plasma optical Emission spectroscopy (ICP - OES) with ultrasonic Nebulizer (USN) the ICP and nitrate $NH_3$by photo colour method (non-colour 500D).

2.4. Flow and solute transport conceptual model

Five models, for the five soil columns, were developed to estimate the flow and transport from the vadose zone to the aquifer system, in which HYDRUS 1D was used. The average depth of the soil columns is 20m, which represents the average depth of the vadose zone. The physicalproperties of the soil layers were measured in the laboratory. These included grain size distribution, porosity, moisture content, and saturated hydraulic conductivity. These data were used to estimate the soil moisture characteristic curve, as will be described in section 3.4.

To determine solute transport and natural attenuation of the vadose zone, HYDRUS 1D Simunek *et al*. (1998) was usedfor the simulation. Hydrus-1D can deal with chemical, and biological processes, including sorption-desorption, volatilization, photolysis, and biodegradation.

2.5. The COCs selection criteria and natural attenuation in the vadose zone

Chemical and biological elements in water are classified into eight groups (suspended solids, biodegradable organics, pathogens, anions, cations, heavy metals, nutrients and pharmaceutical components). Six contaminants of concern COCs (Mg, Cl, Fe, NH_3, NO_3 and Fecal Coliform) were selected to study and to simulate. Mg was selected because soil containing high levels of exchangeable magnesium is often thought to be troubled with soil infiltration problems (FAO 1985). Clwas selected because it is a conservative element and not adsorbed by soils (FAO 1985).For irrigated areas, the chloride uptake by plants depends not only on the water quality but also on the soil chloride. Fe was selected because it is essential for plant growth. However, excessive Fe concentration causesundesirable accumulations in plant (FAO 1985).$NH_3$and NO_3 were selected because the nitrogen components may become a risk for infants, causing blue baby, miscarriages and death in infants(Jovanovic et al. 2008). Fecal Coliform was selected because the microbial mass growing is the primary reason for bio-clogging, which reduces porosity and hydraulic conductivity (Thullner et al. 2003)

From the previous studies: In the Dan Region reclamation project in Tel Aviv, the soil aquifer treatment purifies the effluents by processes of slow sand filtration, precipitation, adsorption and ion exchange through 15m vadose zone. Iceksonet *al.* (1997) indicated that Cl is not attenuated in the vadose zone. Due to the nature of the chloride ion, its concentration is only reduced by dilution in the saturated zone.

Soils are capable of removing heavy metals from solution by cation exchange and adsorption. After secondary treated wastewater recharge to limestone aquifer with 7m sand dune vadose zone the reduction inFe was 62% after 25 months Bekele *et al.* (2011). Sewage irrigation caused 55.1% and 81.7% increases in Pb and Fe, respectively, over the well water irrigated plots through sand soil Al Omron *et al.* (2011).

Waly*et al.* (1987) stated that magnesium was reduced following travel through the vadose zone with depth and with time due to leaching of the initial salt content, absorption and ion exchange.

Fecal Coliform (FC) bacteria were removed by filtration and by absorption during passage of the watering secondary effluent through granite rock soil (Itoyama *et al.*, 1990). Bacteria removal occurred within the first 0.35 m of vadose subsoil for all effluent types for three types of soil consisting of gravel, sand, silt and clay from two sites (O'Luanaigh *et al.*, 2012). Guessab *et al.* (1993) observed removal efficiencies up to 99.9% for FC. At the flushing Meadows in Arizona, FC were reduced from 3500 CFU/100ml to 0.3 CFU/100ml during travelling through vadose zone with 3m depth (Bouwer *et al*, 1984).

2.6. Solute transport and reaction parameters for the COCs as input for HYDRUS 1D

Soil contaminant transport parameters and reaction parameters were the model inputs, which include: bulk density, longitudinal dispersivity, diffusion coefficients, and adsorption isotherm coefficient. The dispersion coefficients (Disp) were obtained from the literature as per Vanderborght and Vereecken (2007) for each soil texture. Diffusion coefficients in free water (D_d) for Mg, Cl, Fe, $NH_3$and NO_3 for sandy soil are6.10, 17.54, 5.22, 14.17 and 16.43 e-5 m^2/d, respectively (Domenico and Schwartz, 1990). Diffusion coefficient in soil air (Da) was set to zero.

Adsorption isotherm coefficient k_d $[M^{-1}L^3]$ is a factor related to the partitioning of a contaminant between the solid and aqueous phases. It is a ratio between sorbed metal concentration and dissolved metal concentration. The adsorption isotherm coefficient values for Mg, Cl, Fe, $NH_3$and NO_3 for sandy soil are 0.001, 1.2 e-6, 0.142, 7.8e-7 and zerom^3/g, respectively (Serne2007), (Garcia *et al*. 2009), (Krupka 2004), (Jiajie *et al*. 2013), (Jovanovic *et al.* 2008) and (Napier & Snyder 2002).

For NH3 nitrification rate constant $T^{-1}$and for NO3 denitrification rate constant T^{-1} are very important parameters, which represent the conversions of NH3 and NO_3 in nitrogen cycle. NH3 nitrification rate constant is 0.05 $day^{-1}$and NO_3 denitrification rate constant is 0.0015 day^{-1}(Xuezhi *et al.* 2015), (Jiajie *et al.* 2013),(Zwang *et al*. 2013) and (Tesorierol *et al.* 2011).

3. Results and Discussion

3.1. Porosity and hydraulic conductivity measurement

The soil porosity and hydraulic conductivity were determined experimentally for 98 soil samples using the oven drying method and constant head test and using the following equations.

$$n = \frac{V_v}{V_t} = \frac{V_a+V_w}{V_s+V_a+V_w} = \frac{V_t-V_s}{V_t} \quad (2)$$

$$K = \frac{q}{Ai} = \frac{QL}{Qht} \quad (3)$$

Where, n = porosity, V_v= voids volume, V_a= air volume, V_w= water volume, V_s= soil particles volume, V_t= total volume, K = saturated hydraulic conductivity, Q = volumeof water collected in time t, A = cross sectional area of sample, h = difference in manometer levels, i = hydraulic gradient, and L = distance between manometer tapping points.

The saturated hydraulic conductivity for the soil samples was measured using the constant head test shown in Figure 3. The test was repeated for each soil sample three times at three constant heads (110.5, 95.5 and 65.5 cm).Figure 4 shows the values of porosity and hydraulic conductivity for each soil sample.

Figure 3. Constant head permeability test apparatus

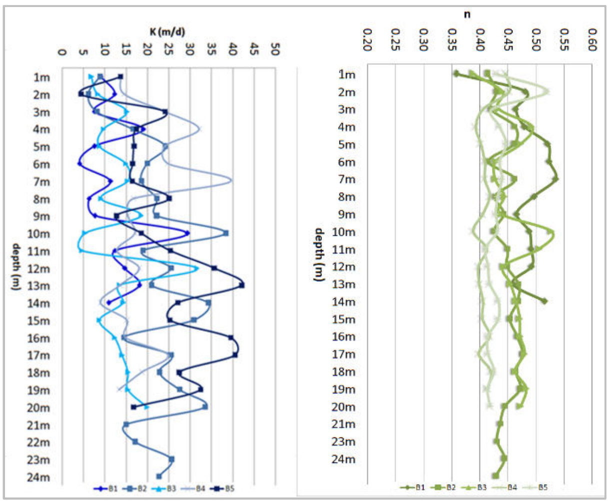


Figure 4. Porosity and hydraulic conductivity values for 98 samples for 5 boreholes

3.2. Wastewater and groundwater sampling analysis

Water sampling was conducted for primary, secondary and tertiary treated wastewater and for water collected from the oxidation pond. The analysis was conducted to obtain the concentration of contaminants of concern at two-hoursintervalover 24-hours period in winter and summer. Samples were stored for 24 hours at 4^{o} C in pre-sterilized high-density polyethylene (HDPE) containers for chemical and biological analysis. To interpret the results the mean concentrations over the 24 h-sampling period werecalculated.

Table 1. Mean values for COC concentrations for wastewater and groundwater (mg/l)

parameter	Primary	Secondary	Oxidation pond	Tertiary	B1	B2	B3	B4	B5
Mg	19.06	20.56	14	13.03	17	18	16	29.25	37
Cl	243.47	195.02	196	113.6	50	43.98	60.99	200	335.3
Fe	6.25	1.8	0.245	0.397	0.7	0.964	0.5	0.36	0.33
NH_3	25.25	15	13.42	1.83	0	0	0	0	0
NO_3	52.8	15	16	95.5	1	1	5	21.8	10.1

3.3. Soil analysis

For particle size distribution analysis grain size tests were conducted on 98 soil samples by sieve analysis through sieve #4 at top to sieve #200 at bottom using a mechanical shaker. For chemical analysis one soil sample was collected from each borehole. Soil samples were dried and sieved through a 2 mm sieve and kept for chemical analysis. Samples were stored at 4±2 °C until analyzed.

The results of the chemical analysis showed that boreholes 2 and 3 have the highest concentrations followed by boreholes 4 and 5, whereas, contaminants concentrations at borehole 1 were lower. The field observations justify these results as the wells located within or close to theforest area, which is being irrigated with wastewater after oxidation pond, has higher concentrations compared to those located within or close to areas irrigated with groundwater.

Table 2. Chemical characteristics of soil samples (mg/kg)

parameter	B1	B2	B3	B4	B5
Mg	8.192	192.928	136.576	114.704	1.824
Cl	85.2	2442.4	3424.88	1192.8	28.4
Fe	5380	10740	9773	3774	4915
NH_3	26.2	25.8	42.8	558.7	41.9
NO_3	17.5	163.3	96	74.8	549.1

3.4. Estimation of soil moisture characteristic curve

Soil hydraulic parameters are required by vadose models to characterize the hydraulic behavior of the soil system.In this study, 98 soil samples were collected, one sample for each meter over the entire depth of each borehole. The borehole depths are14, 24, 20, 19, 20m for B1, B2, B3, B4 and B5, respectively. Sieve analysis was conducted on the samples to determine the grain size to be used in Zapata et al (2000) model (D60) to determine the soil moisture characteristiccurve (SMCC).

$$\theta(\varphi) = c(\varphi)\frac{\theta_s}{\ln\left(e+\left(\varphi/a_f\right)^{n_f}\right)^{m_f}} \tag{4}$$

$$c(\varphi) = 1 - \frac{\ln(\varphi/\varphi_r)}{\ln(10^6/\varphi_r)} \tag{5}$$

$$a_f = 0.8627\, D_{60}{}^{-2.751} \tag{6}$$

$$n_f = 7.5 \tag{7}$$

$$m_f = 0.1772\, ln\, D_{60} + 0.7734 \tag{8}$$

$$\frac{\varphi_r}{a_f} = \frac{1}{D_{60}+9.7e^{-4}} \tag{9}$$

Where, θ_s is the saturated volumetric water content, φ_r is the matric suction corresponding to the residual water content (θ_r),a_f, n_f and m_f are model parameters.

To determine Van Genuchten's fitting parameters (α,n) Van Genuchten's equation was fitted to the above curves using a solver in Excel.

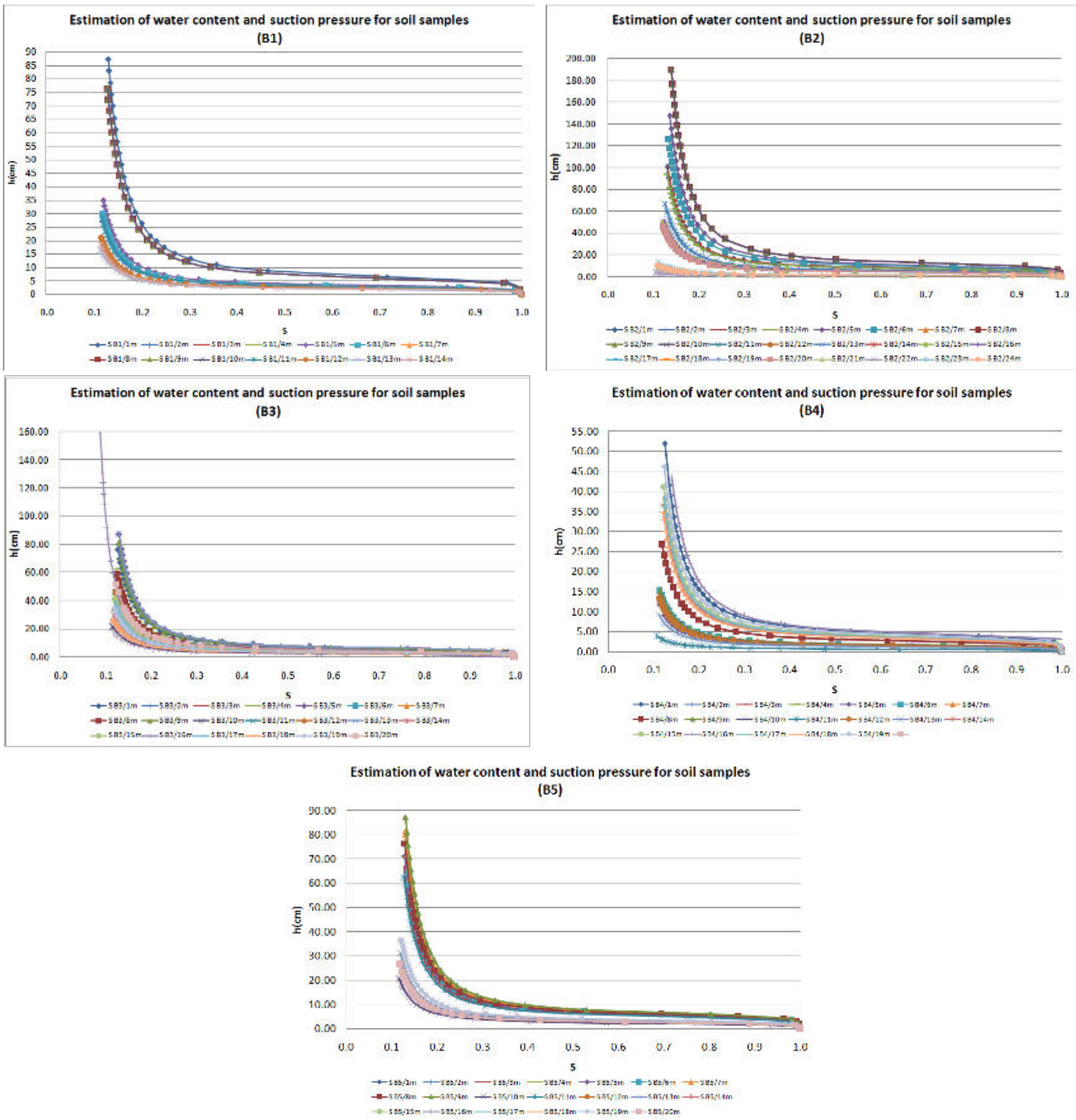


Figure 5. Soil moisture characteristic curve

3.5. *Water flow simulation with HYDRUS 1D*

The HYDRUS-1D model (Simunek et al., 1998) was used to simulate flow for 5 soil columns in the pilot area in Sadat city with total depths 18, 24, 20, 19, and 20 m for B1, B2, B3, B4, and B5, respectively, which correspondto the depth of water table. The simulation time was set at 50 years (18250 days). The starting simulation year was 1992 and the end year was 2042. The van Genuchten-Mualem single porosity model was selected, without hysteresis as shown in the following equations.

$$\theta(\mathrm{h}) = \begin{cases} \theta r + \frac{\theta s - \theta r}{(1+|ah|^{b})^{c}} & h < 0 \\ \theta s & h \geq 0 \end{cases} \tag{10}$$

$$\mathrm{K(h)} = K_s \left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^{0.5} [1-\left(1-\left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^{1/m}\right)^{m}]^2 \tag{11}$$

Where K_s is the saturated hydraulic conductivity [LT^{-1}]; θ_r is residual water content; θ_s is the saturated water content; α is an empirical constant that is inversely related to the air-entry pressure value [L^{-1}]; m and n are empirical parameters related to the pore-size distribution.

Each soil profile was divided into sub-regions according to sieve analysis and permeability test results. Soil hydraulic parameters and fitting parameters for each sub-region (shown in Table 3) were calculated based on soil water characteristic curve.

The initial conditions are set as linear gradient from 0 at the groundwater table and -14.2, -15.6, -14.6, -9.6, and -15m at the surface(x=0) to 3.8, 8.4, 5.4, 9.4, and 5m at the column base (x=depth) for B1, B2, B3, B4, and B5, respectively. The time variable boundary condition was employed to represent the variations in irrigation flux and the variation in groundwater table.

For upper boundary condition, it was assumed to have variable flux at the surface layer according to the irrigation scenario.For the lower boundary, a variable pressure head is assigned based on the variation in groundwater table with time at year 1992, 2002, and 2014 as shown in Figure 7.

Table 3. Soil hydraulic parameters for each sub-region

Depth	θ_r	θ_s	α	n	Ks	Depth	θ_r	θ_s	α	n	Ks
Borehole No (1)							Borehole No (4)				
Sub-region 1	0.047	0.359	0.1440	3.3182	9.12	Sub-region 1	0.050	0.425	0.6392	3.7051	13.60
Sub-region 2	0.057	0.489	0.3841	3.7143	13.15	Sub-region 2	0.048	0.402	0.3098	3.7322	24.53
Sub-region 3	0.060	0.487	0.2381	3.4900	7.38	Sub-region 3	0.045	0.393	0.5613	3.9702	32.15
Sub-region 4	0.055	0.469	0.3876	3.7160	18.60	Sub-region 4	0.046	0.405	0.6274	3.8152	24.51
Sub-region 5	0.062	0.524	0.3354	3.6572	4.18	Sub-region 5	0.046	0.409	0.6170	3.8989	39.54
Sub-region 6	0.064	0.525	0.3253	3.5876	11.14	Sub-region 6	0.049	0.407	0.4144	3.7718	16.59
Sub-region 7	0.063	0.488	0.1604	3.3507	29.35	Sub-region 7	0.049	0.406	0.2866	3.4569	8.98
Borehole No (2)							Borehole No (5)				
Sub-region 1	0.056	0.421	0.1286	3.5177	7.73	Sub-region 1	0.053	0.429	0.2544	3.4817	13.23
Sub-region 2	0.045	0.362	0.4518	3.1497	12.79	Sub-region 2	0.061	0.520	0.3653	3.6161	4.44
Sub-region 3	0.061	0.453	0.1321	3.4299	22.45	Sub-region 3	0.054	0.423	0.1777	3.4042	24.17
Sub-region 4	0.060	0.425	0.0760	3.3774	38.37	Sub-region 4	0.055	0.434	0.2421	3.4473	17.11
Sub-region 5	0.056	0.460	0.3303	3.6520	26.03	Sub-region 5	0.053	0.427	0.2559	3.5214	26.06
Sub-region 6	0.056	0.455	0.2335	3.5368	32.84	Sub-region 6	0.049	0.414	0.3653	3.6161	35.67
Sub-region 7	0.058	0.467	0.2155	3.5360	14.47	Sub-region 7	0.050	0.415	0.3474	3.6149	40.73
Sub-region 8	0.048	0.429	0.7507	4.0508	22.69	Sub-region 8	0.050	0.413	0.2851	3.5206	32.48
Borehole No (3)											
Sub-region 1	0.058	0.462	0.2144	3.6097	8.16						
Sub-region 2	0.054	0.450	0.2277	3.5625	14.78						
Sub-region 3	0.062	0.506	0.2360	3.6288	4.69						
Sub-region 4	0.055	0.443	0.2360	3.6288	31.61						
Sub-region 5	0.059	0.473	0.2903	3.6660	16.95						

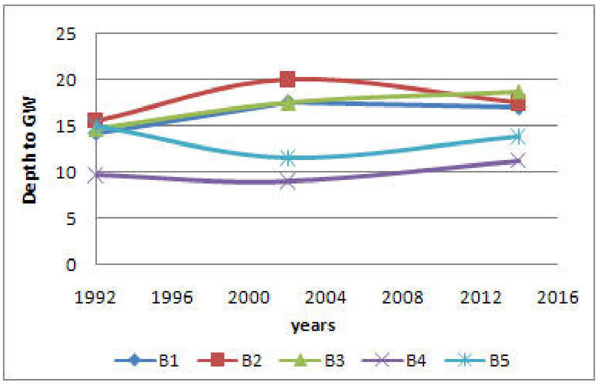


Figure 7. Variation in depth to groundwater with time

For the five soil profiles, the upper boundary conditions were set to zero. The results indicated that the bottom fluxes were affected by the variations in depth to groundwater table. Negative bottom cumulative fluxes indicate downward movement of water from the vadose zone to the groundwater table. The positive bottom cumulative fluxes indicate upward movement and the groundwater feeds the vadose zone as shown in Figure 8.

On the other hand, sixirrigation scenarioswereapplied for the five soil profiles. In these scenarios, the upper boundary condition was set as variable flux at the surface layer. For five scenarios the irrigation rate was equal to 15 m^3/fed/d = 0.00357 m/d and for the sixth scenario the irrigation rate was double flux equal to 30 m^3/fed/d = 0.00714 m/d.The average water requirement equals to 0.001317 m/d = 5.5 m^3/fed/d and the max water requirement is 0.00221 m/d = 9.28 m^3/fed/d(R. R. Ali et al, 2012). The upper boundary condition equals to the irrigation rate minus average water requirement 0.0.00357-0.001317 = 0.00225 m/d. And for the double flux scenario the upper boundary condition equals to 0.00714-0.001317 = 0.005826 m/d. The surface flux was setas a negative number because water enters the system.

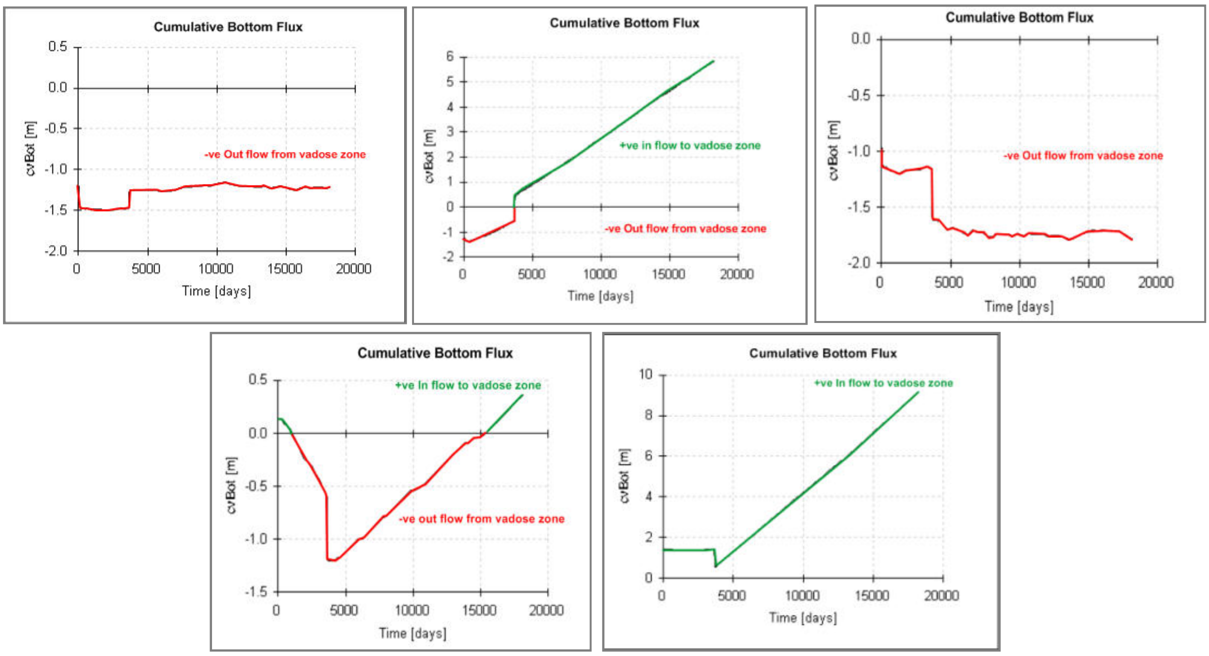


Figure 8. Simulated cumulative water fluxes at the bottom boundary for each borehole according to irrigation scenario

3.6. Solute transport simulation with HYDRUS 1D

The HYDRUS-1D model was used to simulate solute transport. The program solves the advection dispersion equation for solute transport. Five models were used to simulate the contaminants of concern to define the process occurring in the vadose zone.

Fivecontaminants of concern (Mg, Cl, Fe, NH_3 and NO_3) were simulated; simulation duration was taken 10220 days from 2014 to 2042.

Soil transport parameters needed for solute transport simulation are bulk density (ρ_b [ML^{-3}]) for each sub-region, longitudinal dispersivity, adsorption isotherm coefficient (k_d [$M^{-1}L^{-3}$]), anddiffusion coefficient (D_d)

Initial concentration valueswere assigned at each node of the soil profile [mass of solute/volume of water]. The initial value of the adsorbed concentration was estimatedfrom the soil chemical sampling analysis as shownabove.The liquid phase concentration was calculated from the following equation.

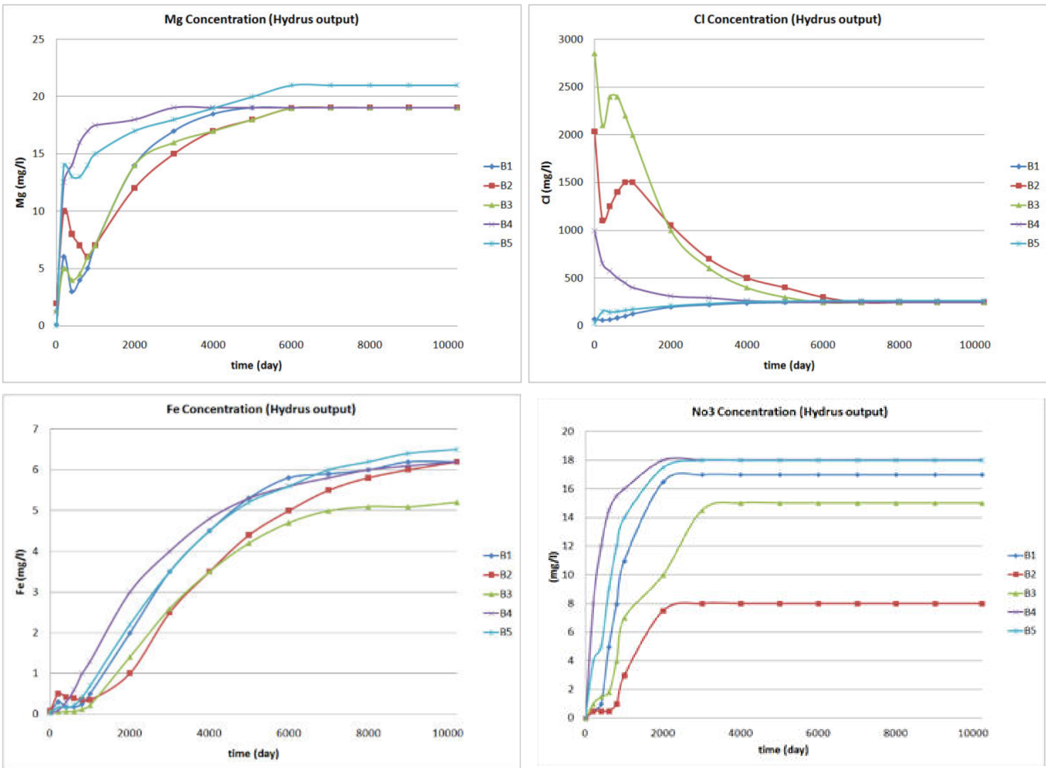
$$Kd\ [L^3M^{-1}] = \frac{\mathit{The\ initial\ value\ of\ the\ adsorbed\ concentration}\ [MM^{-1}]}{\mathit{The\ liquid\ phase\ concentration}\ [M\ L^{-3}]} \qquad (12)$$

Table 4. The initial values of the liquid phase concentration (g/m^3)

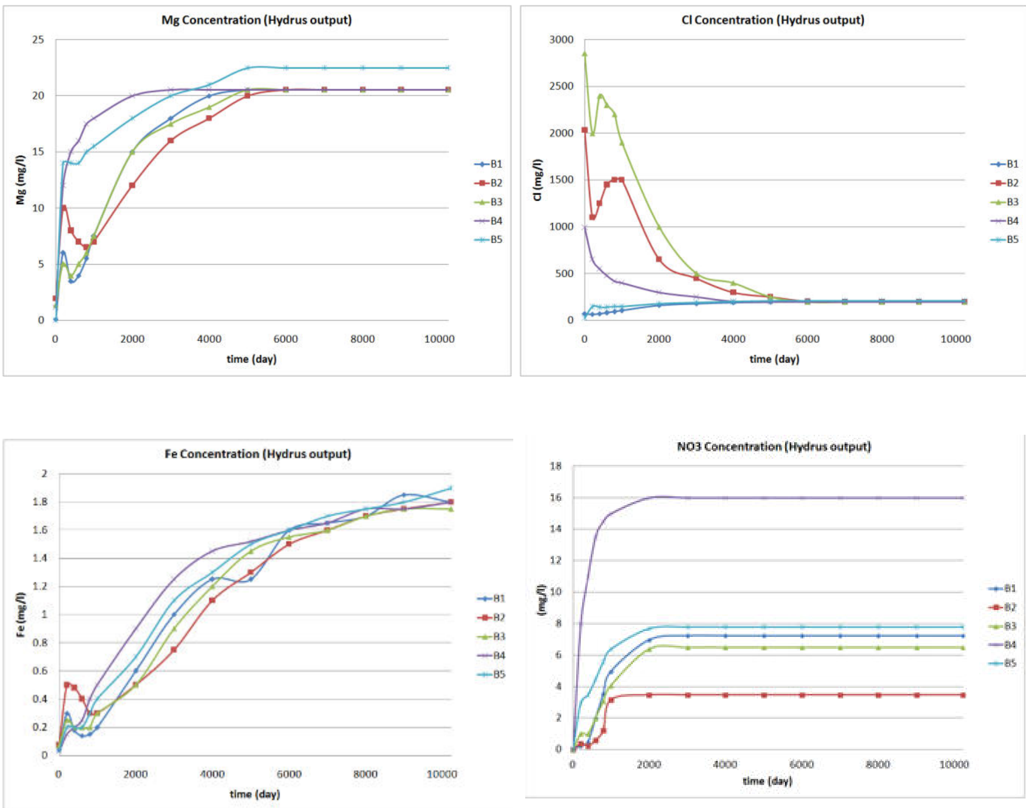
Parameter (mg/kg = µg/g)	B1	B2	B3	B4	B5
Magnesium Mg	0.08	1.93	1.37	1.15	0.02
Chloride Cl	71	2035.3	2854.1	994	23.7
Iron Fe	0.0379	0.0756	0.0688	0.0266	0.0346
Ammonia NH_3	0.001641	0.001611	0.002672	0.034921	0.002620
Nitrate NO_3	0	0	0	0	0

Concentration flux boundary conditionwas set for the upper boundary according to the irrigation scenario. Six irrigation scenarios were simulated based on the irrigation water quality (primary, secondary, oxidation pond, tertiary treated wastewater, tertiary treated wastewater with double flux = 5.826 mm/d and the last scenario is irrigation with two year rotation(primary treated wastewater and groundwater).

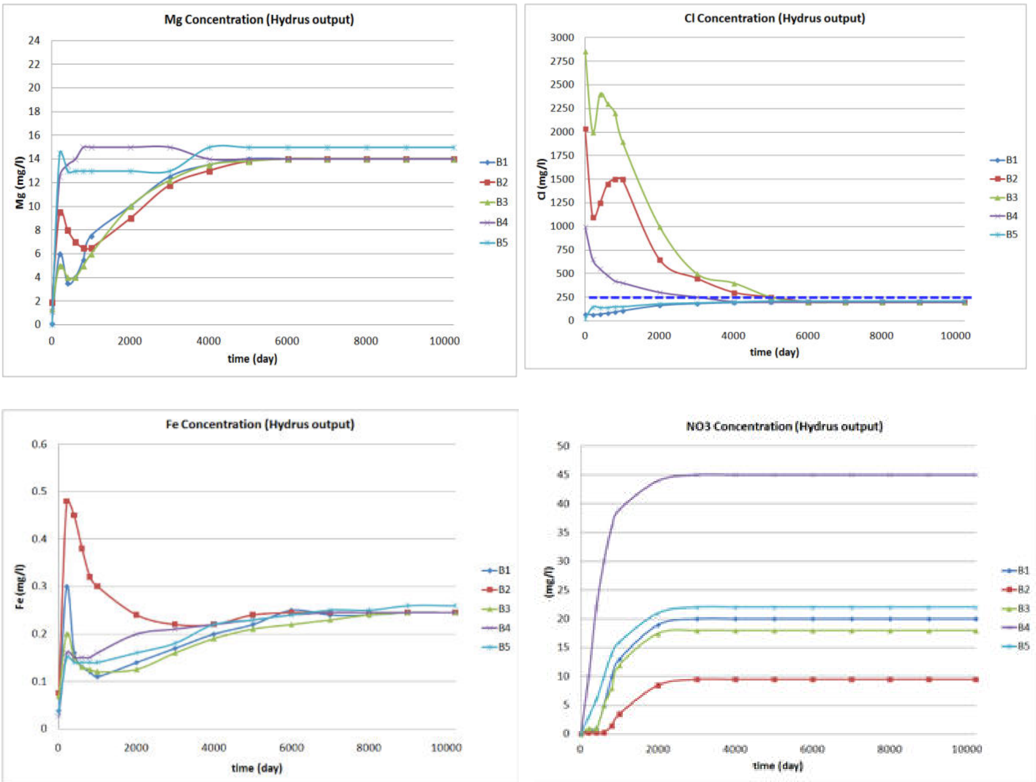
Figures (9 a, b, c, d, e& f) show the contaminant concentrationswith time up to year 2042 after the purifications and the soil leaching at the bottom node, which is directly above the groundwater table. The results indicate that the contaminant concentrations are sensitive to the initial concentration of the soil.



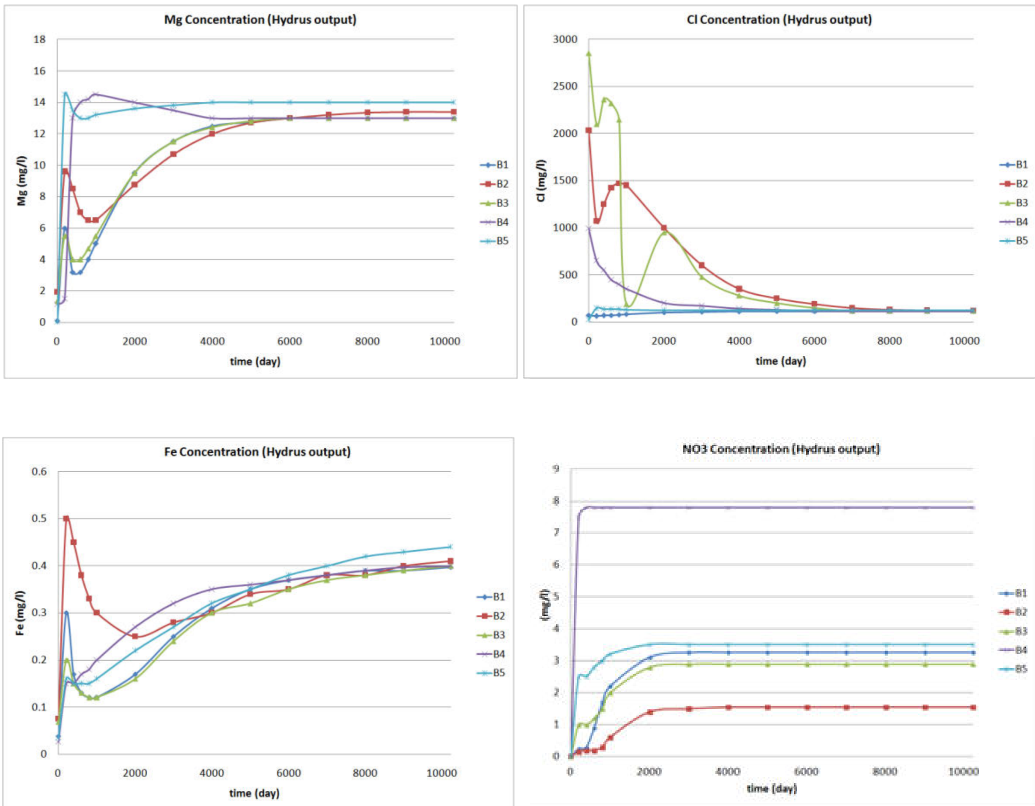
a)



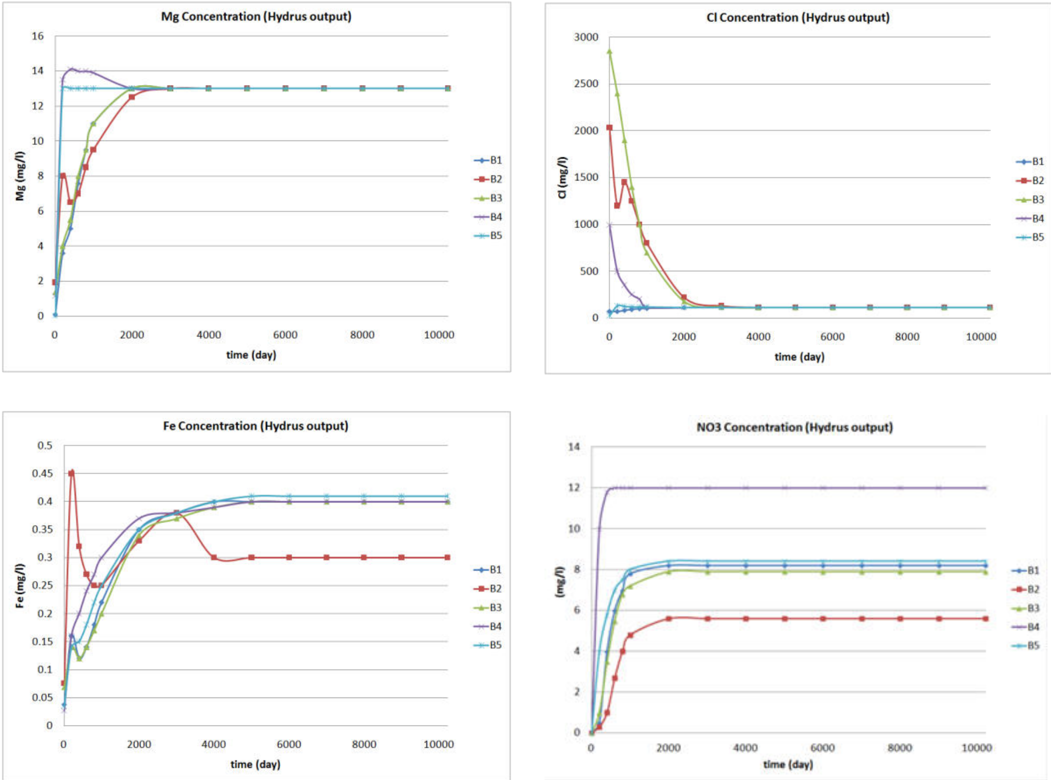
b)


Mg Concentration (Hydrus output)
Mg (mg/l)
time (day)
B1
B2
B3
B4
B5
Cl Concentration (Hydrus output)
Cl (mg/l)
time (day)
Fe Concentration (Hydrus output)
Fe (mg/l)
time (day)
NO3 Concentration (Hydrus output)
(mg/l)
time (day)

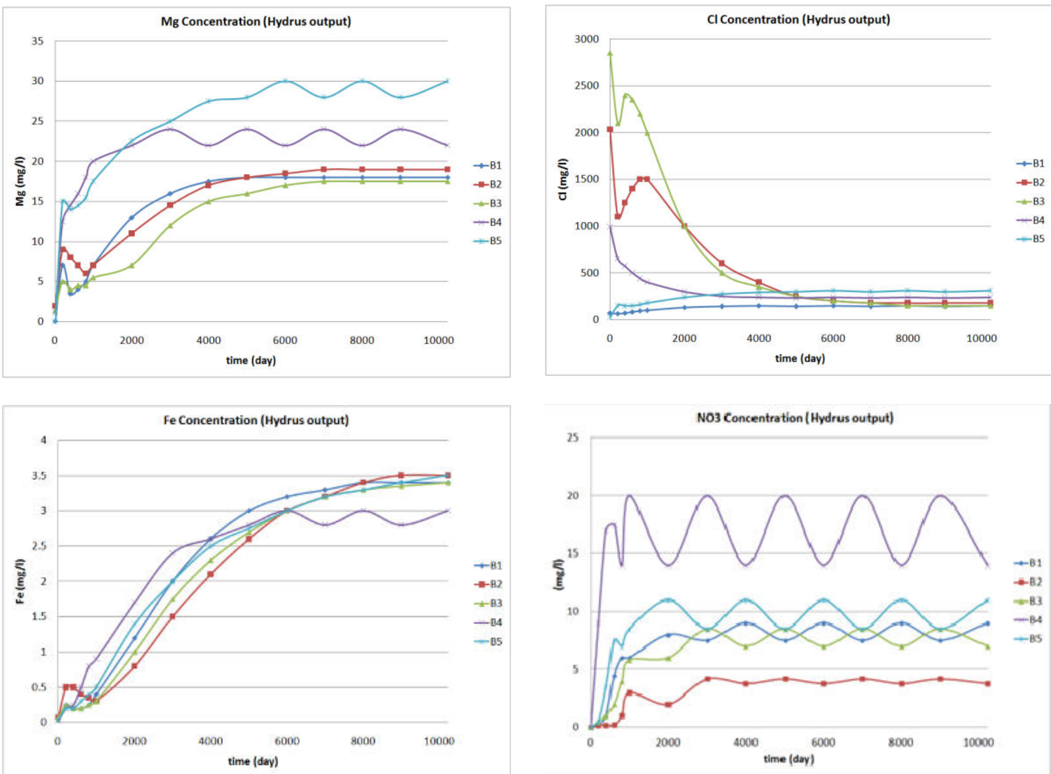
c)


Mg Concentration (Hydrus output)
Mg (mg/l)
time (day)
B1
B2
B3
B4
B5
Cl Concentration (Hydrus output)
Cl (mg/l)
time (day)
Fe Concentration (Hydrus output)
Fe (mg/l)
time (day)
NO3 Concentration (Hydrus output)
(mg/l)
time (day)

d)



e)



f)

Figure 9. Concentration reaching to groundwater

3.7. Bio-clogging

Ham *et al.*(2007), Seki (2013) and Thullner, *et al.*(2003) definedbio-clogging as the change in porosity and hydraulic conductivity of aporous medium due to microbial growth. In unsaturated porous media, the microbial mass grows in the pores then the pores clog, this consequently reduces the hydraulic conductivity. Column experiments were carried out to study the bio-clogging of sand columns due to bacteria attachment. Numerical models were usedto study the effect of biomass growth on hydraulic conductivity and porosity. To study the effect of biomass growth on soil properties,Thullner model (2003)was used:

$$K_r = \frac{K}{K_{clean}} = a\left(\frac{\beta - \beta_{min}}{1-\beta_{min}}\right)^3 + (1-a)\left(\frac{\beta - \beta_{min}}{1-\beta_{min}}\right)^2 \leq 1$$

$$\beta = \frac{\theta_m}{\theta}$$

$$\theta_m = \theta - \theta_{bio} = \theta - \frac{\rho_b C}{\rho_{biomass}}$$

Where K_r is the relative permeability, *a*: fitting parameter (-2 , -0.5) = -1.7, β: relative mobile porosity, θ_m: mobile porosity θ_{bio}: immobile biomass porosity, *C*: concentration (mg/l), ρ_b: bulk density, $\rho_{biomass}$: bacteria density = $1.086*10^6$ mg/l *Ham et al.* [2007], β_{min}: is a threshold value for the relative mobile porosity, i.e., the value of β where the hydraulic conductivity reaches zero, given the constraint $\beta \in]\beta_{min},1]$. (0.5, 0.65, 0.75, 0.8).

Thullner model (2003) was applied using the laboratory and field data for the five boreholes. Four bacteria concentrations were used, primary water: 8,000,000 cfu/100 ml, secondary water: 29,500 cfu/100 ml, oxidation ponds: 920,000 cfu/100 ml and tertiary: 26,916 cfu/100 ml. The results indicated that the main changes occur in scenario (1) (irrigation with primary wastewater).The ratio of hydraulic conductivity (accounting for bio-clogging)tooriginal hydraulic conductivity ranges from: for borehole (1): 81% - 98%, for borehole (2): 95% - 99%, for borehole (3): 96% - 99%, for Borehole (4): 95% - 99% and For borehole (5): 96% - 99%. The reduction in hydraulic conductivity occurs: in borehole (1): for all layers, for borehole (2): for layers No 5, 6, 7, for borehole (3): for first 7 layers, for borehole (4): for first 6 layers, for borehole (5): for first 3 layers as shown in Figure 10.

4. Conclusion

The impacts of reusing treated wastewater for irrigation on soil and the natural attenuation through the vadose zone at Sadat city are assessed according to different irrigationscenarios and through the conducting of field investigations, lab analysis and computer simulations

Five boreholes within the study area were assessed. According to the results, the concentrations of contaminants of concern were higher in boreholes No2 & No3 and lower in boreholes No1, 4 and 5. The results indicated that the area which was located in the forest area has high concentrations compared to other areas irrigated with well water and virgin soil.

The vadose zone simulation and SMCC are sensitive to the soil hydraulic parameters. From solute transport simulation, the results indicate that the concentrations of COCs were highly affected by the initial concentration of soil and soil contaminant transport parameters and reaction parameters, longitudinal dispersivity, diffusion coefficients, adsorption isotherm coefficient, nitrification rate constant and denitrification rate constant.

The presented results show the variation in the concentration of COCs at the bottom of the soil column with initial concentration, irrigation water quality and irrigation rate.

According to the bio-clogging analysis the microbial growth effects on hydraulic conductivity and causes soil bio-clogging with reduction of about1 to 20% As expected, primary wastewater has the highest impact on soil bio-clogging.

According to the irrigation scenarios simulation results, the preferred scenarios are the third scenario (irrigation with oxidation pond water), fourth scenario (irrigation with tertiary treated wastewater) and fifth scenario (irrigation with tertiary treated wastewater with double irrigation rate). For the case under investigation, the results of these scenarios show that the concentrations of COCs after purification through the vadose zone which will reach to the groundwatertable are lower than the WHO limits.

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data used in this research.

Figure 10. Hydraulic conductivity values for five boreholes after bio-clogging

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